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Mobile Antennas

NIJ Standard 0205.01

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James K. Stewart, Director
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Mobile Antennas

NIJ Standard-0205.01
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National Institute of Justice

James K. Stewart, Director

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FOREWORD

This document, NIJ Standard-0205.01, Mobile Antennas, is an equipment standard developed by the Law Enforcement Standards Laboratory of the National Bureau of Standards. It is produced as part of the Technology Assessment Program of the National Institute of Justice (NIJ). A brief description of the program appears on the inside front cover.

This standard is a technical document that specifies performance and other requirements equipment should meet to satisfy the needs of criminal justice agencies for high quality service. Purchasers can use the test methods described in this standard to determine whether a particular piece of equipment meets the essential requirements, or they may have the tests conducted on their behalf by a qualified testing laboratory. Procurement officials may also refer to this standard in their purchasing documents and require that equipment offered for purchase meet the requirements. Compliance with the requirements of the standard may be attested to by an independent laboratory or guaranteed by the vendor.

Because this NIJ standard is designed as a procurement aid, it is necessarily highly technical. For those who seek general guidance concerning the selection and application of law enforcement equipment, user guides have also been published. The guides explain in nontechnical language how to select equipment capable of performance required by an agency.

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Before citing this or any other NIJ standard in a contract document, users should verify that the most recent edition of the standard is used. Write to: Chief, Law Enforcement Standards Laboratory, National Bureau of Standards, Gaithersburg, MD 20899.

Lester D. Shubin
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National Institute of Justice

NIJ STANDARD FOR MOBILE ANTENNAS

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COMMONLY USED SYMBOLS AND ABBREVIATIONS

A	ampere	H	heary	nm	nanometer
ac	alternating current	h	hour	No.	number
AM	amplitude modulation	hf	high frequency	o.d.	outside diameter
cd	candela	Hz	hertz (c/s)	Ω	ohm
cm	centimeter	i.d.	inside diameter	p.	page
CP	chemically pure	in	inch	Pa	pascal
c/s	cycle per second	ir	infrared	pe	probable error
d	day	J	joule	pp.	pages
dB	decibel	L	lambert	ppm	part per million
dc	direct current	L	liter	qt	quart
°C	degree Celsius	lb	pound	rad	radian
°F	degree Fahrenheit	lbf	pound-force	rf	radio frequency
diam	diameter	lbf·in	pound-force inch	rh	relative humidity
emf	electromotive force	lm	lumen	s	second
eq	equation	ln	logarithm (natural)	SD	standard deviation
F	farad	log	logarithm (common)	sec.	section
fc	footcandle	*M*	molar	SWR	standing wave radio
fig.	figure	m	meter	uhf	ultrahigh frequency
FM	frequency modulation	min	minute	uv	ultraviolet
ft	foot	mm	millimeter	V	volt
ft/s	foot per second	mph	mile per hour	vhf	very high frequency
g	acceleration	m/s	meter per second	W	watt
g	gram	N	newton	λ	wavelength
gr	grain	N·m	newton meter	wt	weight

area = unit^2 (e.g., ft^2, in^2, etc.); volume = unit^3 (e.g., ft^3, m^3, etc.)

PREFIXES

d	deci (10^{-1})	da	deka (10)
c	centi (10^{-2})	h	hecto (10^2)
m	milli (10^{-3})	k	kilo (10^3)
μ	micro (10^{-6})	M	mega (10^6)
n	nano (10^{-9})	G	giga (10^9)
p	pico (10^{-12})	T	tera (10^{12})

COMMON CONVERSIONS
(See ASTM E380)

ft/s × 0.3048000 = m/s
ft × 0.3048 = m
ft·lbf × 1.355818 = J
gr × 0.06479891 = g
in × 2.54 = cm
kWh × 3 600 000 = J

lb × 0.4535924 = kg
lbf × 4.448222 = N
lbf/ft × 14.59390 = N/m
lbf·in × 0.1129848 = N·m
lbf/in^2 × 6894.757 = Pa
mph × 1.609344 = km/h
qt × 0.9463529 = L

Temperature: $(T_{°F} - 32) \times 5/9 = T_{°C}$

Temperature: $(T_{°C} \times 9/5) + 32 = T_{°F}$

NIJ STANDARD FOR MOBILE ANTENNAS

1. PURPOSE AND SCOPE

This document establishes minimum performance requirements and methods of test for mobile antennas mounted on vehicles used by law enforcement agencies, and deals with antenna characteristics that determine the suitability and effectiveness of antennas for law enforcement use. As a result, only the following four frequency bands are considered: 25–50 MHz, 150–174 MHz, 400–512 MHz, and 806–866 MHz. This standard supersedes NILECJ-STD-0205.00, Mobile Antennas dated May 1974. This revision has been written to include mobile antennas operating in the 806–866 MHz frequency band, and it also provides a substantially improved standard radiation test site that uses an elevated metal ground plane. In addition, the relative antenna gain requirement and test method have been replaced by a gain-transfer requirement and test method.

2. CLASSIFICATION

For the purposes of this standard, mobile antennas are classified by their operating frequency, polarization, and radiation pattern. The antennas to be tested are assumed to be primarily vertically polarized, omnidirectional radiators. However, antennas having directional radiation patterns may be tested using the techniques set forth in this standard with the restriction that the antenna radiating structure must have a maximum horizontal dimension of one-half wavelength.

2.1 Operating Frequency

2.1.1 Type I

Antennas that operate in the 25–50 MHz frequency band.

2.1.2 Type II

Antennas that operate in the 150–174 MHz frequency band.

2.1.3 Type III

Antennas that operate in the 400–512 MHz frequency band.

2.1.4 Type IV

Antennas that operate in the 806–866 MHz frequency band.

2.2 Radiation Pattern

2.2.1 Omnidirectional Antennas

2.2.2 Directional Antennas

3. DEFINITIONS

The principal terms used in this document and defined in this section are those used in IEEE standard publications for antennas [1,2].[1] Additional definitions relating to law enforcement communications are given

[1] Numbers in brackets refer to the references in appendix A.

in LESP-RPT-0203.00, Technical Terms and Definitions Used with Law Enforcement Communications Equipment [3].

3.1 Dipole Antenna

A linear antenna that produces a radiation pattern approximating that of an elementary electric dipole. It is usually a metal radiating structure supporting a line current distribution similar to that of a thin straight wire so energized that the current has a node only at each end.

3.2 Directional Antenna

An antenna having the property of radiating or receiving electromagnetic waves more effectively in some directions than others.

3.3 Gain

The gain of an antenna, in a specified direction, that is 4π times the ratio of the power radiated per unit solid angle in that direction to the net power accepted by the antenna from the connected transmitter. This quantity is an inherent property of the antenna and is not affected by system losses arising from a mismatch of impedance or polarization. When the direction is not stated, the gain is usually taken to be the gain in the direction of its maximum value.

3.4 Gain-Transfer Measurement

A method of measurement in which the unknown realized gain of a test antenna is measured by comparing it to that of a gain-standard antenna. The test antenna is illuminated by a plane wave that is polarization matched to it, and the received power is measured. The test antenna is replaced by a gain-standard antenna, leaving all other conditions the same and the received power is again measured. The realized gain of the test antenna is equal to the realized gain of the standard antenna plus the ratio, in dB, of the power received by the test antenna to that received by the standard antenna.

3.5 Insertion Loss

The ratio, in dB, of the power level indicated by the receiver with the signal generator connected directly to the receiver through any required transmission lines, to the power level indicated by the receiver with the same transmission lines attached to a two-port network. For this standard, the two-port network is a pair of monopole antennas and the propagation path between them.

3.6 Mismatch Loss

The ratio, in dB, of the incident power to the transmitted power at the antenna feedpoint. It may be calculated, using the SWR, as follows:

$$\text{Mismatch Loss} = 10 \log_{10} [(\text{SWR} + 1)^2/(4\ \text{SWR})], \text{ in dB.}$$

3.7 Monopole Antenna

An antenna, constructed above an imaging plane, that produces a radiation pattern approximating that of an electric dipole in the half-space above the imaging plane.

3.8 Omnidirectional Antenna

An antenna having an essentially nondirectional pattern in azimuth and a directional pattern in elevation.

3.9 Power Rating

The maximum continuous power in the operating frequency band that can be applied to the antenna, in accordance with the standard duty cycle, without temporarily degrading its performance below specified limits.

3.10 Radiation Pattern

A graphical representation of the radiation properties of the antenna as a function of space coordinates. Usually, for dipole and monopole antennas, the radiation pattern is determined in the far-field region and is represented as a function of directional coordinates having the origin at the antenna feedpoint. The radiation property of interest in this standard is realized gain at a zero degree elevation angle.

3.11 Realized Gain

The gain of an antenna in its environment, reduced by the losses due to the mismatch of the antenna input impedance to a specified impedance.

3.12 Standing Wave Ratio (SWR)

The ratio of the maximum to the minimum values of voltage in the standing wave pattern that appears along a lossless transmission line having the antenna as the terminating load.

4. REQUIREMENTS

4.1 Minimum Performance

The mobile antenna performance shall meet or exceed the requirement for each characteristic as given below.

4.2 User Information

The information supplied to the user by the manufacturer or distributor shall include the following:

(a) Operating frequency band
(b) Antenna gain (realized gain)
(c) Radiation pattern
(d) SWR
(e) Power rating
(f) The materials used to fabricate the antenna

4.3 Test Sequence

Each antenna tested shall first be subjected to the vibration and power rating tests. It shall then be tested for conformance with sections 4.6, 4.7, and 4.8 using test equipment and transmission lines (cables) having nominal impedances equal to 50 Ω.

4.4 Vibration Stability

There shall be no deterioration in either the structural integrity or the electrical performance of the antenna when subjected to the vibration test described in section 5.3.

4.5 Power Rating

There shall be no deterioration in either the structural integrity or the electrical performance of the antenna when subjected to the power rating test described in section 5.4.

4.6 Standing Wave Ratio

The SWR at the antenna feedpoint shall be less than 1.5 when measured in accordance with section 5.5.

4.7 Radiation Pattern

4.7.1 Omnidirectional Antenna

When the radiation pattern of the antenna is measured in accordance with section 5.6, the variation from a constant value shall be ≤1.0 dB throughout the total 360° in azimuth.

4.7.2 Directional Antenna

When the radiation pattern of the antenna is measured in accordance with section 5.6, the variation from the pattern specified by the manufacturer shall be ≤1.0 dB throughout the azimuth angle specified for the major lobe.

4.8 Gain Transfer

The variation in the realized gain of the antenna, measured in accordance with section 5.7, shall be within 1.0 dB of the specified value.

5. TEST METHODS

5.1 Standard Test Conditions

Energize the measurement equipment long enough to achieve the stability prescribed in the instruction manuals prior to performing the measurements. Measure all electrical antenna parameters at the antenna feedpoint, i.e., the electrical connector specified by the manufacturer as the point at which the transceiver connects to the antenna. If the feedpoint is at the end of a cable attached to the antenna by the manufacturer, ensure that this cable remains attached to the antenna for all tests. Unless otherwise specified perform all measurements under standard test conditions.

5.1.1 Standard Radiation Test Site

The test site shall consist of an elevated metal ground plane having a surface flatness within ±0.5 cm (±0.2 in) for Type III and Type IV tests and within ±1 cm (±0.4 in) for the lower frequency tests. The dimensions of the ground plane shall be at least 3.7 by 4.9 m (12 by 16 ft) for Type I tests. If tests are to be made only in the higher frequency bands, the size of the ground plane may be reduced by a scale factor equal to 90/(lowest desired test frequency in MHz). The ground plane is extended with 16 equally spaced radials, approximately 0.25 λ long and lying in the plane of the ground plane. These radials, which may consist of stretched wires or extensible whips, are attached to 240-Ω resistors located at approximately equal angular spacings (measured from the center of the ground plane) along the periphery of the ground plane. See figure 1 for details. The ground plane is elevated at any convenient height to allow access to the feedpoints of the test and gain-standard antennas. No general rules can be made for determining the required distance of reflecting objects from the ground plane because the distance depends upon the angular size of the object viewed from the ground plane and its orientation as a possible reflector (polarization and location of the test antenna images when the reflector is assumed to be a mirror). Reflections may be determined by observing the measured swept-frequency insertion loss between pairs of gain-standard monopoles over the frequency band of interest. Reflections are not a problem if the curve is a smooth function of frequency having no cyclical variations in amplitude exceeding ±1 dB.

5.1.2 Standard Duty Cycle

The standard duty cycle shall be 5 min with rated power applied to the antenna feedpoint followed by 15 min with no power applied, repeated three times.

5.1.3 Test Frequencies

Tests shall be conducted at any of the operating frequencies specified by the manufacturer or distributor (sec. 4.2(a)).

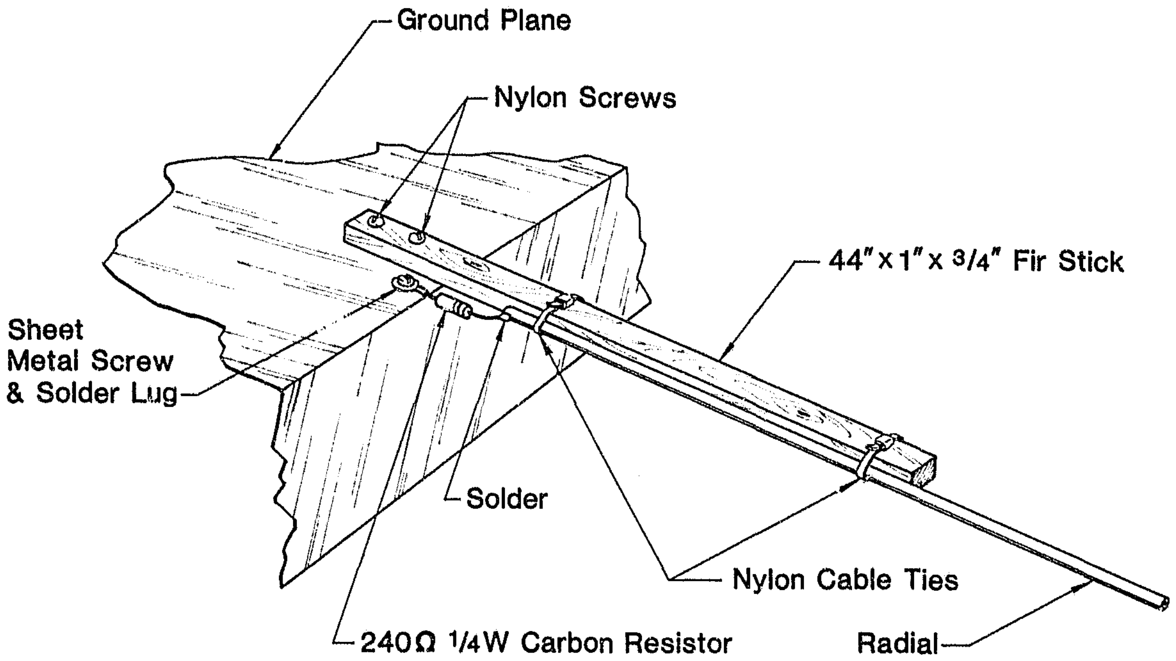


FIGURE 1. *Attachment of the 240 Ω resistor between the ground plane and the wire radials.*

5.2 Test Equipment

The test equipment described in this section is the minimum required to perform the antenna SWR, radiation pattern, and gain-transfer measurements. All other equipment shall be of comparable quality.

5.2.1 Gain-standard Monopole Antennas

Type I gain-standard monopole antennas are fabricated using extensible whips or brass tubing having a 1 cm (≈0.4 in) diameter at the feedpoint, and Type II, III, and IV gain-standard monopole antennas are fabricated using brass tubing with a 0.48 cm (3/16 in) outer diameter in accordance with the procedures given in [4]. Calculated gains and mismatch losses for the gain-standard monopole antennas are given in tables 1 through 4.

TABLE 1. *Type I gain-standard monopole antenna parameters (diameter = 1 cm (0.394 in)).*

Frequency, MHz	*Length, m*	*Gain, dB*	*Mismatch loss, dB*	*Realized gain, relative to isotropic, dB*
25	2.43	4.8	4.2	0.6
26	2.43	4.8	3.0	2.0
27	2.43	4.8	1.7	3.1
29	2.43	4.8	0.28	4.6
31	2.43	4.8	0.34	4.5
33	2.43	4.9	1.3	3.6
35	2.43	4.9	2.4	2.4
35	1.72	4.8	4.4	0.4
36	1.72	4.8	3.4	1.4
37	1.72	4.8	2.5	2.3
38	1.72	4.8	1.7	3.1
41	1.72	4.8	0.2	4.6
44	1.72	4.8	0.4	4.5
47	1.72	4.9	1.3	3.5
50	1.72	4.9	2.4	2.5

TABLE 2. *Type II gain-standard monopole antenna parameters (diameter = 0.48 cm (0.189 in)).*

Frequency, MHz	Length, m	Gain, dB	Mismatch loss, dB	Realized gain, relative to isotropic, dB
150	0.445	4.8	1.2	3.7
152	0.445	4.8	0.9	4.0
155	0.445	4.8	0.5	4.3
157	0.445	4.8	0.3	4.5
159	0.445	4.8	0.2	4.6
162	0.445	4.8	0.1	4.7
164	0.445	4.8	0.1	4.7
166	0.445	4.8	0.2	4.6
169	0.445	4.8	0.3	4.5
171	0.445	4.8	0.4	4.4
174	0.445	4.8	0.6	4.2

TABLE 3. *Type III gain-standard monopole antenna parameters (diameter = 0.48 cm (0.189 in)).*

Frequency, MHz	Length, m	Gain, dB	Mismatch loss, dB	Realized gain, relative to isotropic, dB
400	0.156	4.7	1.6	3.2
417	0.156	4.7	0.84	3.8
434	0.156	4.6	0.37	4.2
453	0.156	4.4	0.14	4.3
491	0.156	4.4	0.31	4.1
512	0.156	4.2	0.62	3.6

TABLE 4. *Type IV gain-standard monopole antenna parameters (diameter = 0.48 cm (0.189 in)).*

Frequency, MHz	Length, m	Gain, dB	Mismatch loss, dB	Realized gain, relative to isotropic, dB
806	0.0845	4.5	0.26	4.3
821	0.0845	4.5	0.17	4.3
835	0.0845	4.4	0.12	4.3
851	0.0845	4.4	0.085	4.3
866	0.0845	4.3	0.079	4.2

5.2.3 Power Meter

A power meter, used with a directional coupler, shall be used to measure the incident and reflected power with an accuracy of ±7 percent or better. A directional wattmeter may be substituted.

5.2.4 Transmitter

A transmitter or CW signal generator and power amplifier combination, having a power rating that is equal to or greater than the antenna being tested, shall be used to verify the antenna power rating.

5.2.5 Signal Generator

A CW signal generator with an input SWR of 2.0 or less and capable of producing a 0 dBm minimum signal level over the test frequency ranges of interest, may be used for antenna SWR, radiation pattern, and gain-transfer measurements. See section 5.2.9.

5.2.6 Receiver

A receiver with an input SWR of 2.0 or less and having a measurement range of +10 to −60 dBm or greater, that covers the test frequency ranges of interest, may be used for the radiation pattern and gain-transfer measurements. Its amplitude nonlinearity shall be ±0.3 dB or less over any 10 dB portion of the measurement range. See section 5.2.9.

5.2.7 SWR Measuring Device

Any SWR measuring equipment with a residual SWR of 1.15 or less such as a network analyzer, return loss bridge, directional wattmeter, or slotted line may be used (with the signal generator, if required) for SWR measurements.

5.2.8 Attenuator

To improve gain measurement accuracy, a fixed 3 or 6 dB attenuator, having a maximum SWR rating of 1.2 or less, shall be used at the end of the cable attached to the receiver. Use of this attenuator between the receiver and the cable required to attach it to the test antenna feedpoint forces the resulting impedance to be as close to 50 Ω as practical.

5.2.9 Network Analyzer

A network analyzer having a amplitude ratio accuracy of ±0.3 dB may be used instead of the signal generator and receiver for the radiation pattern and gain-measurements described in sections 5.6 and 5.7.

5.3 Vibration Test

Mount the test antenna on a stationary supporting structure in a plane perpendicular to its axis and subject it to simple harmonic motion having an amplitude of 0.076 cm (0.03 in) producing a total excursion of twice this value while varying the frequency slowly between 10 and 60 Hz. If resonance is found, select the frequency at which the most severe resonance occurs and designate it as f. Vibrate the antenna in the same plane with the same amplitude while varying the frequency uniformly from 0.9 to 1.1 f and back to 0.9 f. Repeat this 5-min cycle continually for 4 h. If no resonance is found, vibrate the antenna while the frequency is varied uniformly from 10 to 60 Hz and back to 10 Hz over a 5-min period. Repeat this 5-min cycle continually for 8 h.

5.4 Power Rating Test

Mount the test antenna in the center of the standard radiation test site (sec. 5.1.1) as shown in figure 2. Apply rated power at the feedpoint in accordance with the standard duty cycle. If no physical failure occurs that would make the antenna useless, measure the SWR, radiation pattern, and gain transfer as described in sections 5.5, 5.6, and 5.7.

5.5 Standing Wave Ratio Test

Any of the equipment specified in section 5.2.7 may be used to measure the SWR of the test antenna. Mount the test antenna in the center of the ground plane as shown in figure 2 and measure the SWR at the antenna feedpoint in accordance with the manufacturer's instruction manual.

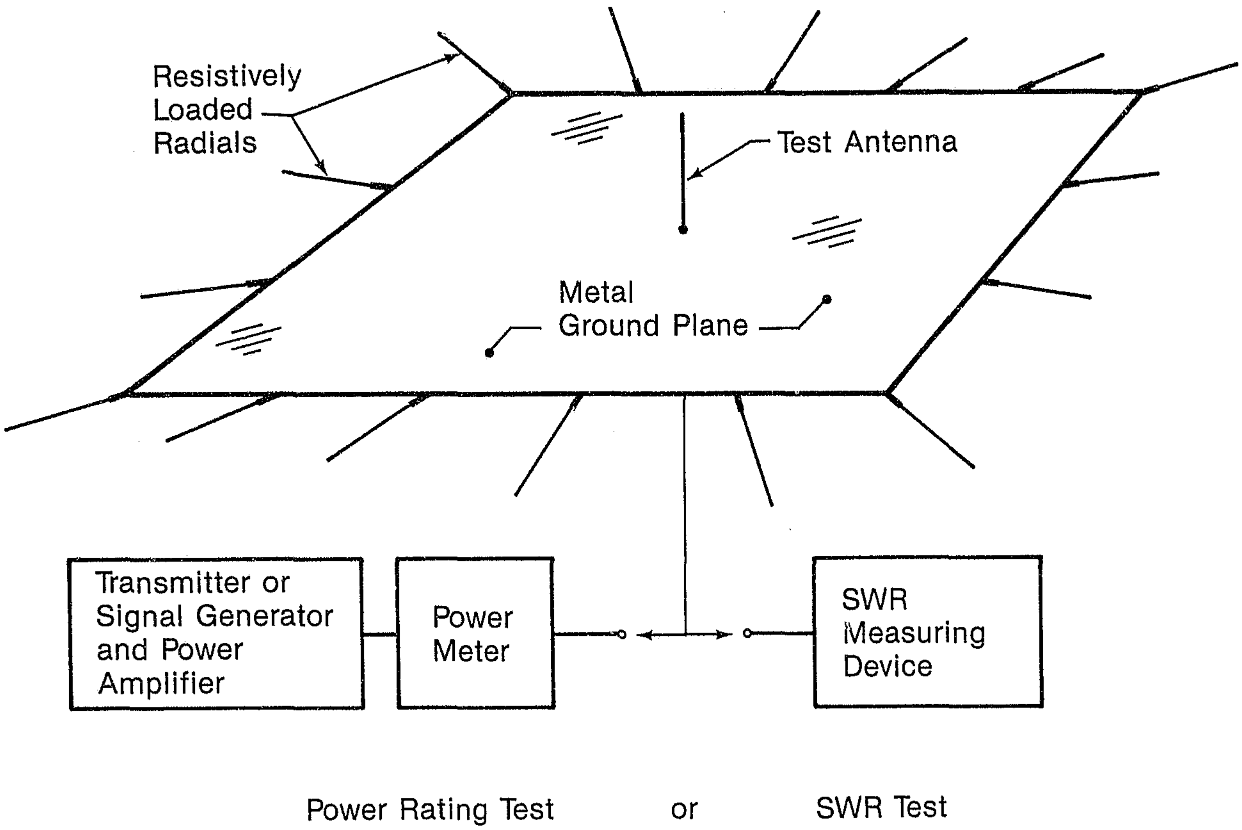


FIGURE 2. *Test setup for measuring antenna power rating or SWR.*

5.6 Radiation Pattern Test

A network analyzer may be used instead of the receiver and CW signal generator specified for this test.

For simple vertical wire test antennas with a length of $\lambda/4$ or less, mount a gain-standard monopole antenna and the test antenna on the ground plane's longitudinal axis, equidistant from the center, at a separation distance $\geqslant\lambda/2\pi$. Other test antennas require a separation distance $\geqslant 2(d)^2/\lambda$, where d is the greatest horizontal dimension of the antenna or twice the maximum height of the antenna, whichever is greater. Attach the receiver and signal generator to the test antenna and a gain-standard monopole, respectively, as shown in figure 3. Measurements may be made anywhere on the ground plane as long as the SWR is the same as it is in the center. Set the signal generator output level to produce a received signal level at least 10 dB above ambient noise and record this level as the initial 0° level. Loosen the mounting fixture, rotate the test antenna 45°, and record the received signal level and azimuth angle. Repeat this measurement every 45° for the full 360° rotation. If the 0° and 360° levels do not agree within 0.3 dB, the equipment has not stabilized or the SWR's of the test antenna, test equipment connectors, or connecting cables are not constant and indicate possible failure. Find the error, correct it and repeat the measurement.

For omnidirectional antennas, if the 0° and 360° levels agree within 0.3 dB but the test antenna radiation pattern is not omnidirectional within ±1 dB, repeat the pattern measurements in 10° increments for a full 360° rotation. The final 0° azimuth position is that at which the maximum received signal level occurs. The received signal level normalized to that of the maximum level in dB, and plotted versus azimuth angle, is the radiation pattern of the test antenna.

For directional antennas, use this test as described above except that the antenna direction pattern need only be measured in increments of 10° from the center of the major lobe to each prescribed edge.

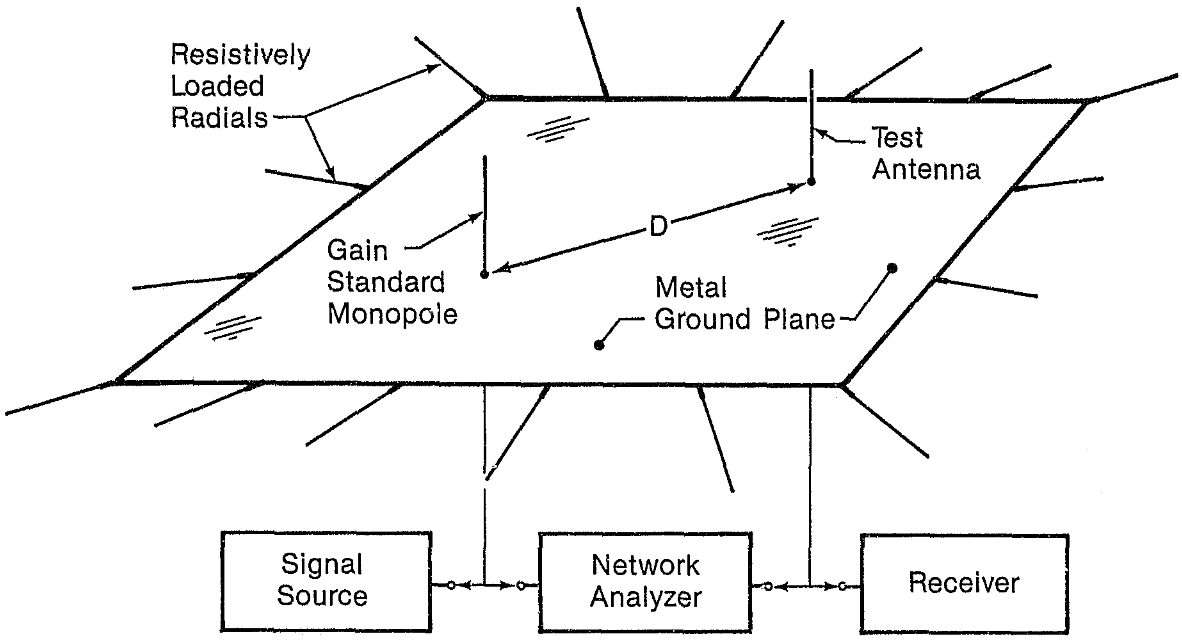
5.7 Gain-Transfer Test

Mount the gain-standard monopole and test antenna on the ground plane as shown in figure 3 and record the received signal level, L_t, for the 0° azimuth position. Replace the test antenna with another gain-standard monopole and record the received signal level, L_s. Calculate the maximum realized gain of the test antenna relative to that of an isotropic antenna as follows:

$$\text{Gain} = \text{Realized gain from tables 1 through 4 (interpolated if necessary)} + (L_t - L_s), \text{ dB.}$$

If a network analyzer is used, attach the two measurement ports of the network analyzer to the test antenna and the gain-standard monopole, and record the insertion loss $s_{12(t)}$. Replace the test antenna with another gain-standard monopole and record $s_{12(s)}$. Calculate the maximum realized gain using $S_{12(t)}$ and $s_{12(s)}$ in lieu of L_t and L_s in the above equation.

If the gain is to be referenced to that of a free-space, half-wave dipole, subtract 2.14 dB from the realized gain calculated above.



Pattern Test and Gain Transfer Test

$D \geq \lambda/2\pi$ for simple vertical wire test antennas with length $\leq \lambda/4$

$D \geq 2(d)^2/\lambda$ for other test antennas

FIGURE 3. *Test setup for measuring antenna pattern or gain.*

APPENDIX A—REFERENCES

[1] IEEE standard test procedures for antennas. IEEE Std. 149-1979 (Revision of IEEE Std. 149-1965). IEEE Inc., New York.

[2] IEEE standard definitions of terms for antennas. IEEE Std. 145-1983 (Revision of ANSI/IEEE Std. 145-1973). IEEE Trans. on Ant. and Prop. Vol. AP-31, Part II of Two Parts. IEEE Inc., New York; 1983 November.

[3] Greene, F. M. Technical terms and definitions used with law enforcement communications equipment. LESP-RPT-0203.00. National Institute of Justice, U.S. Department of Justice, Washington, DC; 1973 July.

[4] FitzGerrel, R. G. Monopole impedance and gain measurement of finite ground planes. NIJ Report 200-87. National Institute of Justice, U.S. Department of Justice, Washington, DC; in press.